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Preliminary Report of Field Descriptions and Contact Relationships of Lithological Units in the South Roby and Twilight Zones, Lac des Iles Deposit, Northwestern Ontario

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ONTARIO GEOLOGICAL SURVEY

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Preliminary Report of Field Descriptions and Contact Relationships of Lithological Units in the South Roby and Twilight Zones, Lac des Iles Deposit, Northwestern Ontario

by

J. Hinchey, K.H. Hattori and M.J. Lavigne

2003

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Abstract

Detailed field mapping was conducted over a period of three months during the 2002 summer field season resulting in the production of maps at scales of 1:60 and 1:120 for the South Roby and Twilight zones, respectively, of the Lac des Iles deposit.

Combined with assay data, the mapping illustrates that the parental magmas of late melanocratic units introduced platinum group elements (PGE) into the ore. The palladium content of late melanocratic units that commonly form the matrix of breccias are much higher than palladium values in earlier leucocratic units. Data from both zones, plotted on Pd versus Cu+Ni diagrams, show a broad positive correlation between Pd and Cu+Ni, indicating that PGE content is controlled by sulphide content. The data suggest primary magmatic mineralization of PGE. Although a broad correlation between Pd and Cu+Ni is observed in samples collected from the Roby Zone, there is a substantial scatter compared to the well-defined correlation from the Twilight Zone. This scatter suggests that late-stage deuteric and/or hydrothermal alteration may have contributed to the mineralization subsequent to the primary magmatic event. This interpretation is also supported by the presence of high-grade mineralization associated with intensely altered high-grade ore that contains high Pd with relatively low Cu and Ni values. This interpretation is also supported by the presence of abundant pegmatitic pods and veinlets, especially in the South Roby Zone. The pods commonly contain quartz, carbonate and hydrous silicate minerals, such as biotite, suggesting volatile-rich parental magmas for the intrusive units. The fluids released from the magmas were likely significant in the redistribution and concentration of PGE.

Preliminary Report of Field Descriptions and Contact Relationships of Lithological Units in the South Roby and Twilight Zones, Lac des Iles Deposit, Northwestern Ontario

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Introduction

Platinum group metals in Ontario are commonly hosted by Sudbury-type nickel-sulphide ore at the base of large mafic intrusions. However, a new variety of this ore-type is becoming important. It is characterized by low contents of sulphide minerals and hosted by mafic intrusions with complex textures and lithologies. The type locality of this new style of palladium ore is the Lac des Iles Mine in northwestern Ontario. This mine is the only primarily palladium-based mining operation in Canada and is hosted by the Lac des Iles mafic to ultramafic intrusive complex of Neoarchean age in the Wabigoon Subprovince of the Superior Province.

This preliminary report documents the geology and mineralization of the South Roby and Twilight zones, at the Lac des Iles Mine, based on detailed mapping at scales of 1:60 and 1:120, respectively, conducted during the 3 months of field work in the summer of 2002. The Lac des Iles Mine is located approximately 85 km north of the city of Thunder Bay. The open pit operation is carried out by North American Palladium Ltd. with measured and indicated resources of 159.4 million tonnes grading 1.55 g/t Pd, 0.17 g/t Pt, 0.12 g/t Au, 0.05% Cu, and 0.05% Ni (Lavigne, Kim and Rickard 2002).

The origin of the deposit has been debated whether the deposit is primarily magmatic or hydrothermal in origin. The focal question remains the cause of high Pd relative to other PGE and the possible role of hydrothermal activity in the concentration of Pd. The major aims of this project are to document the geology of the Pd mineralization, to establish the paragenesis, and to examine the genesis of the Pd mineralization. The research project involves 1) mapping of the mineralized zones, 2) logging and re-logging of selected diamond-drill core samples, 3) determination of the relationships between different lithologic units, 4) evaluation of which magmas introduced Pd, 5) identification and characterization of different styles of alteration and evaluation of any temporal relationship between the different alteration events and mineralization, and 6) the determination of the origin of mineralized mafic pegmatitic and breccia units.

This report focusses on the field observation of the South Roby and Twilight zones and serves as the basis of ongoing petrologic, geochemical, and metallogenic studies of the senior author's PhD thesis at the University of Ottawa. The South Roby Zone is the southern part of the main Roby Zone and is composed of variably altered and mineralized gabbroic units with complicated textures. The Twilight Zone is adjacent to the Roby Zone and consists of relatively unaltered noritic/gabbronoritic units. Palladium contents and lithology vary within a short distance in both zones.

Previous Work and Exploration History

The first mapping of the area was conducted by Joliffe in 1933 as part of reconnaissance mapping project of the Geological Survey of Canada. He produced a map at a scale of 1 inch to 2 miles (1:126 720) (Joliffe 1933). This was followed by detailed (1:31 680 scale) mapping by Pye (Pye 1968) of the Ontario Department of Mines in 1963. Subsequent to increased exploration activity in the area, the Ontario Geological Survey (OGS) conducted numerous mapping projects in the area since 1985. Studies conducted by the OGS include Sutcliffe and Sweeny (1985, 1986), Macdonald (1985, 1988), Macdonald and Lawson (1987), and Sutcliffe, Sweeny and Edgar (1989). Additional geological and metallogenic studies include Watkinson and Dunning (1979), Talkington and Watkinson (1984), Sweeny and Edgar (1987), Brugmann and Naldrett (1987, 1990a, 1990b), Edgar and Sweeny (1991), and Brugmann, Naldrett and Macdonald (1989).

Regional and Local Geology

The following description summarizes previous work mentioned above. The Archean Lac des Iles intrusive complex is a suite of east-northeast-trending mafic plutons, parallel to the boundary with the Quetico Subprovince, ranging from Atikokan to Lake Nipigon (Pye 1968; Sutcliffe 1986). It also forms part of a 30 km diameter ring of mafic and ultramafic plutons, of which the Lac des Iles intrusive complex is the largest (Gupta and Sutcliffe 1990).

The complex is commonly subdivided into 3 units: (1) ultramafic intrusions centred on Lac des Iles termed the North Lac des Iles intrusion, (2) lithologically and texturally complex gabbroic units south of the lake termed the Mine Block intrusion, and (3) a homogeneous hornblende gabbro southwest of Camp Lake termed the Camp Lake intrusion (Lavigne et al. 2001; Watkinson, Lavigne and Fox 2002). These 3 units are interpreted to have been derived from different magma chambers and are separated by tonalitic rocks (Lavigne et al. 2001).

South Roby Zone

DESCRIPTION OF DIFFERENT UNITS

The South Roby Zone represents the only remaining portion of the Roby Zone exposed on the surface. It is located at the southwest corner of the current open pit and serves as an excellent area in which to study the various lithologies and complex textural relationships characteristic of the mineralized zone. The textures of intrusions and their contacts show that they were likely intruded during a short period when earlier intrusions were not totally solidified at the time of later intrusions. The mapping in the summer of 2002 identified 12 different lithological units in the South Roby Zone and these are classified into 3 types: pre-, syn- and post-mineralization. Throughout this report, the term "mineralized" is used to describe the

Photo 1. Medium-grained meso- to melanogabbro breccia from the northern section of the mapped South Roby Zone (mineralized unit 5 in Figure 1). Sulphide ranges from 0 to 5 volume % and consists of disseminated, blebby chalcopyrite-pyrrhotite and sulphide localized along cleavage planes of secondary amphiboles. All clasts are derived from local outcrop material. Note hammer for scale.

Pd-rich units, which may or may not contain sulphide mineralization. The abundance of Pd and sulphide minerals are not necessarily correlated, although the Pd mineralization is commonly accompanied by sulphide minerals (discussed in "Geochemistry").

Pre-mineralization rocks consist of 1) a medium-grained, typically homogeneous anorthositic/leucogabbroic unit (unit 1 on Figure 1, *see* back pocket). The rocks of this unit in proximity to the mineralized units are commonly varitextured with minor amounts of sulphide minerals dominated by pyrite. 2) A fine- to medium-grained, gabbroic unit with moderate alteration where the primary clinopyroxene is replaced by a mixture of actinolite and chlorite (unit 2, Figure 1). When containing a pegmatoidal phase (discussed later), this rock unit is termed "varitextured" gabbro. 3) A medium-grained, homogenous, light-medium grey gabbro unit with locally prominent layering striking at 64 to 68°, defined by alternating layers of plagioclase and clinopyroxene. This unit is moderately to intensely altered with cloudy, sericitized plagioclase and clinopyroxene pseudomorphed by amphiboles and chlorite. This unit commonly contains minor sulphide minerals, consisting of pyrrhotite and chalcopyrite, interpreted to be secondary as they occur along the cleavages of secondary amphiboles (unit 3, Figure 1). 4) This unit, a medium-grained, grey gabbroic unit with local foliation (unit 4, Figure 1), is moderately to strongly altered with sericitized plagioclase and pseudomorphs of clinopyroxene that are composed of secondary amphiboles and chlorite. This unit resembles the barren East Gabbro. These pre-mineralized units contain minor PGE close to the later melanocratic units and pegmatitic phase.

Four units are identified to be syn-mineralization, including 3 mineralized units ranging from melanocratic gabbro to clinopyroxenite, and 1 pegmatite unit. Magma mingling and brecciation are common in these rocks. From north to south, in the South Roby Zone (*see* Figure 1), the 3 mineralized units are 1) a medium-grained, brecciated, meso- to melanogabbro (unit 5, Figure 1; Photo 1), 2) medium- to relatively coarse-grained, intensely altered intrusive breccia with clinopyroxenite matrix (unit 6, Figure 1; Photo 2), and 3) a medium-grained, dark gabbro (unit 7, Figure 1; Photo 3). The pegmatite unit is associated with the 3 mineralized units throughout the map area.

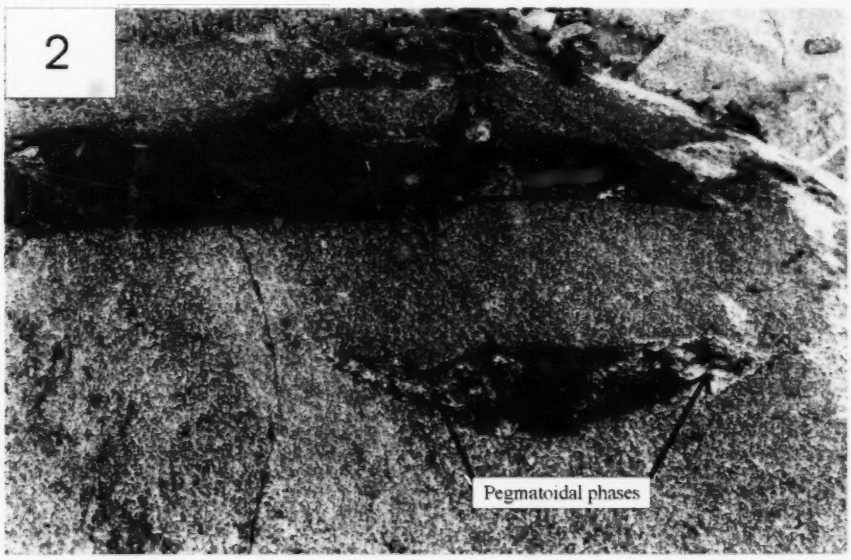


Photo 2. Small mineralized clinopyroxenitic dike intruding medium-grained gabbroic unit from the central section of the mapped South Roby Zone (mineralized unit 6 in Figure 1). Sulphide within the dike ranges from 1 to 5 volume % consisting dominantly of chalcopyrite and pyrrhotite. Within this area, assay results indicate approximately 4.5–5.0 g/t Pd from the clinopyroxenitic unit compared to less than 0.5 g/t for the earlier gabbro. Note the presence of coarse-grained pegmatoid associated with the clinopyroxenitic pod. The spatial relationship between the melanocratic units and pegmatite suggests that the parental magmas for the intrusive units were probably enriched in volatile phases.

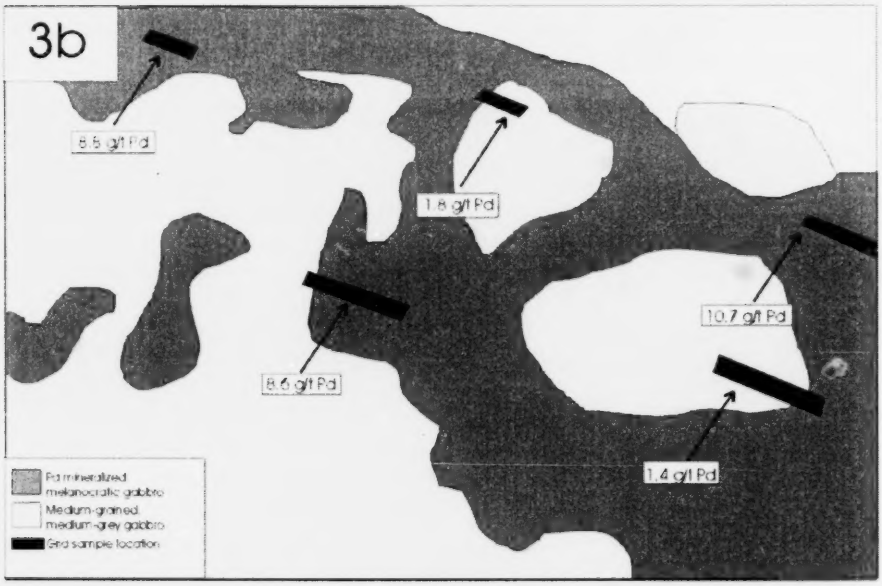


Photo 3. a) Magma mingling between medium-grained, medium-grey gabbroic unit (unit 4, Figure 1) and melanocratic, mineralized gabbroic unit (unit 7, Figure 1) from the southern extent of the mapped South Roby Zone. The melanocratic unit commonly contains 3 to 5 volume % disseminated chalcopyrite and pyrrhotite, whereas the earlier, medium-grey gabbroic unit is typically devoid of sulphides. Within this area, assay results indicate that the melanocratic mineralized unit contains greater than 5 g/t Pd (up to 10.7 g/t Pd), whereas the earlier gabbroic unit typically contain less than 0.2 g/t Pd. b) Sketch from photo illustrating magma mingling and distribution of Pd-mineralization.

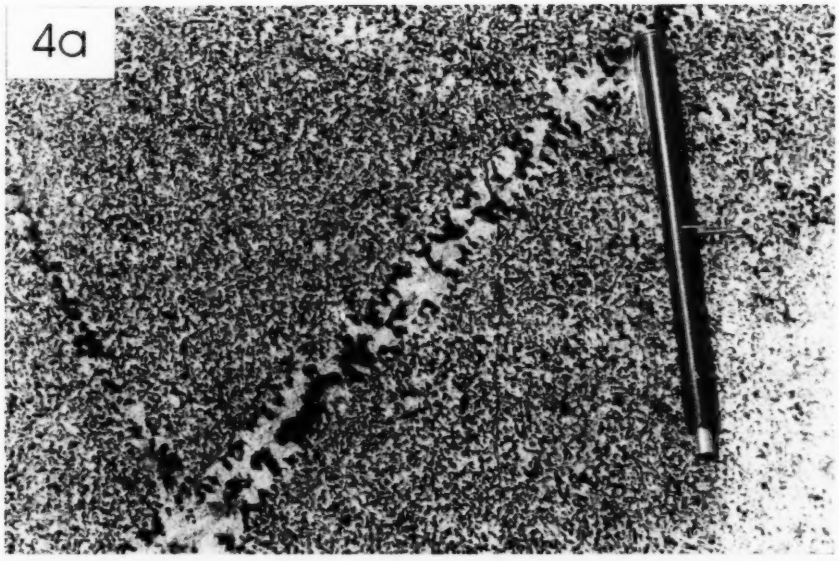
1. Medium-grained brecciated mesogabbro to melanogabbro:
   This unit has variable compositions with clinopyroxene ranging from 45 to 80 volume %. It is moderately to intensely altered with variably saussuritized plagioclase and clinopyroxene replaced by amphiboles and chlorite. The contents of disseminated chalcopyrite and pyrrhotite vary up to 5 volume %. The sulphide minerals are commonly localized along cleavage planes of secondary amphiboles. Blebby sulphide minerals comprise of a mixture of intergrown chalcopyrite and pyrrhotite. Pyrite is common, but pentlandite is not apparent in hand specimens. Fine-grained carbonate is common in the aggregates of sulphide minerals.

2. Medium- to relatively coarse-grained, intensely altered intrusive breccia with clinopyroxenite matrix:
   This unit, although dominantly clinopyroxenite in composition, also varies locally into a clinopyroxene-rich melanogabbro. Clinopyroxene is altered to secondary amphiboles and chlorite. The unit ranges from massive, black altered clinopyroxenite to clinopyroxenite with rubbly brown oxidation on the surface. Sulphide minerals are disseminated chalcopyrite and pyrrhotite with minor pyrite and their contents vary from less than 1 up to 5 volume %. As with the previous unit, some sulphide minerals are of secondary origin occurring along cleavage planes of secondary amphiboles. Primary sulphide minerals also occur as disseminated blebs of intergrown chalcopyrite and pyrrhotite.

3. Medium-grained dark gabbroic unit:
   This unit occurs in the southern portion of the map area (*see* Figure 1). This unit has been termed melanogabbro by previous workers due to the presence of dark coloured minerals including plagioclase. However, it is defined here as gabbro because the mafic mineral content is consistently less than 60 volume %. Moderate alteration has formed variable amounts of sericite in plagioclase and amphiboles and chlorite in clinopyroxene. This unit commonly contains disseminated sulphide minerals (2 to 5 volume %) dominated by intergrown chalcopyrite and pyrrhotite.

4. Pegmatite unit:
   A pegmatite unit forms veinlets and pods (unit 8, Figure 1; Photos 4a and 4b). They are spatially associated with Pd-rich gabbroic-clinopyroxenite rocks (*see* Photo 4b). The pegmatite consists of variably altered, coarse-grained plagioclase and clinopyroxene. The alteration has formed sericite in plagioclase and secondary amphiboles/chlorite in clinopyroxene. The pegmatitic pods are commonly zoned with quartz-rich cores and plagioclase- and pyroxene-rich rims. They commonly contain quartz, biotite, magnetite/ilmenite blebs in addition to variable amounts of sulphide minerals dominated by pyrite with lesser amounts of chalcopyrite. The sulphide aggregates commonly contain fine-grained carbonate grains. The preliminary electron probe analyses indicate that the carbonate is calcite.

Post-mineralization units consist of 1) a late-stage, medium-grained, medium-green clinopyroxenite unit (unit 9, Figure 1) crosscutting earlier units; this unit commonly displays magma mingling with the mineralized clinopyroxenite unit; 2) a late-stage, medium-grained, salt-and-pepper-textured gabbroic unit; 3) late-stage granitic dikes; and 4) late-stage diabasic dikes.



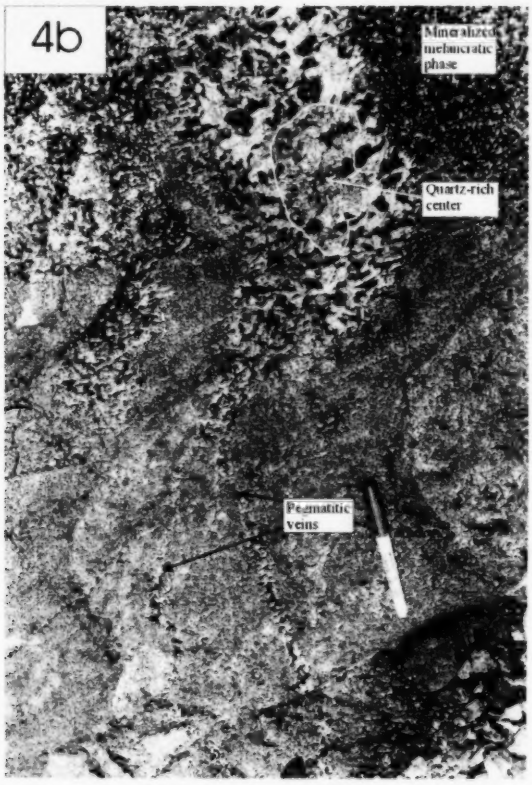


Photo 4. a) Small pegmatitic gabbro veinlet (unit 8, Figure 1) cutting fine-medium grained gabboic unit (unit 2, Figure 1) (South Roby Zone). Such gabbroic units containing abundant pegmatoidal pods and veins have been termed "varitextured gabbro". Note the inward growth (comb-texturing) of the clinopyroxene crystals that are replaced by secondary amphiboles. b) Coarse-grained, pegmatitic pod (unit 8, Figure 1) within a gabbroic unit (unit 3, Figure 1) from the South Roby Zone. The pod is spatially associated with melanocratic, mineralized intrusive material. Note that the pod is a continuation of narrow pegmatitic veinlets, such as illustrated in Photo 4a. Also note the quartz-rich centre of the pegmatitic pod. In addition to quartz, these pegmatitic pods commonly contain biotite, magnetite, ilmenite, and pyrite.

RELATIONSHIPS OF DIFFERENT PHASES IN THE SOUTH ROBY ZONE

Contacts of different units show variable relationships ranging from well-defined intrusive contacts to more diffuse, magma mingling textures. As with the descriptions given above, the contact relationships will be described by dividing lithologies into pre-, syn- and post-mineralization.

Relationships between the various pre-mineralization units are difficult to establish due to the lack of their exposures except for the intrusion of the anorthositic unit into the varitextured gabbroic unit with a sharp boundary.

The contacts between the mineralizing units and the pre-mineralizing units are well displayed in outcrop of the South Roby Zone. These mineralized units occur as the matrix to breccia (*see* Photos 1 and 2) where pre-mineralized units form well-defined fragments. The mineralized phase intruded into partially solidified pre-mineralization phases, forming magma-mingling textures (*see* Photo 3).

The magmatic breccia occurs in the northern portion of the South Roby Zone and the matrix is composed of the above-described medium-grained, melanogabbro unit. This breccia contains subangular to rounded clasts of all the previously described pre-mineralization rocks. The magmatic breccia intruded the fine- to medium-grained, massive pre-mineralization gabbroic rocks (unit 2, Figure 1). "Varitextured" gabbro is locally developed in this unit, as described above, due to exsolution of fluids from mineralized phases. The other 2 mineralized units intruded other pre-mineralization rocks. However, instead of forming breccias, these units mingled with the partially crystallized earlier phases (*see* Photo 3) and form dikes with well-defined intrusive contacts (*see* Photo 2). As illustrated in Photo 5, breccia locally changes to interfingering and magma-mingling of 2 units.

In many cases, pegmatitic and/or varitextured gabbro marks the boundary between mineralized units and pre-mineralization intrusions (Photo 6). These pegmatitic rocks locally sharply cut earlier phases. It should also be noted that these pegmatitic veins are isolated on the outcrops, but they are commonly connected to larger pegmatitic pods (*see* Photo 4b).

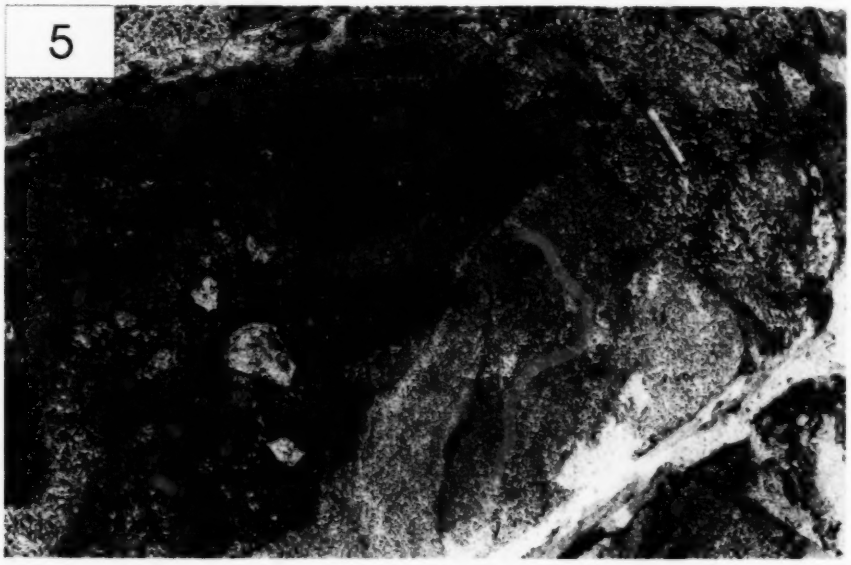


Photo 5. Magma mingling illustrated by the interfingering of a melanocratic, mineralized intrusive unit and medium-grey earlier gabbro unit (South Roby Zone). This suggests that the earlier unit was not totally solidified at the time of the intrusion of the mineralized magma. Note localized breccia texture in the mineralizing unit.

Post-mineralization units intrude earlier units with sharp intrusive contacts, but there is no chilled margins. Furthermore, magma mingling with the earlier lithologies is common, suggesting that the post-mineralization units intruded while earlier units were semi-solidified. The late-stage granitic and diabasic dikes cut all other units, confirming that they intruded at much later time. The granitic dikes are accompanied by an alteration halo (up to 20 cm in width) containing chlorite and secondary amphiboles.

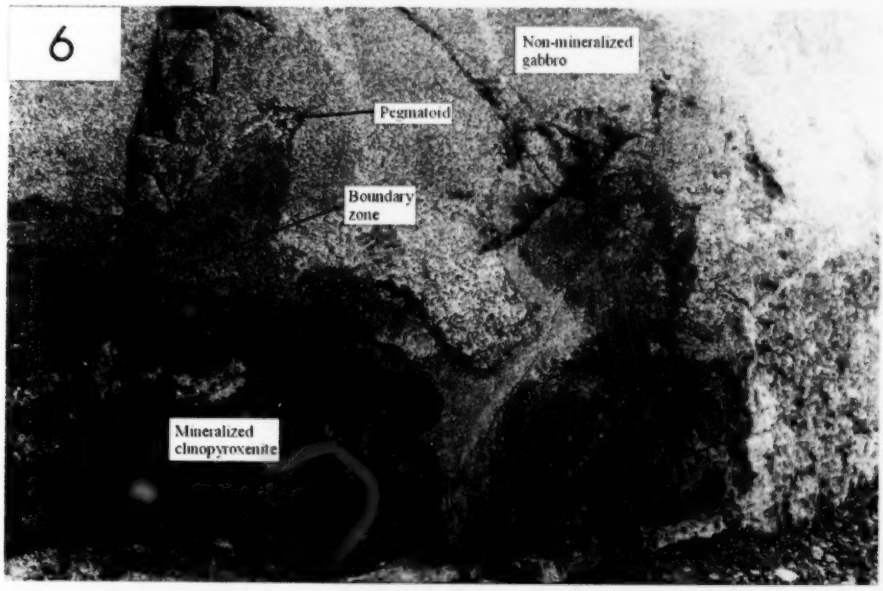


Photo 6. Boundary zone developed along the contact between mineralized clinopyroxenite and gabbroic units (South Roby Zone). Note the occurrence of a pegmatitic pod at the margin of the boundary zone. Note that the coarse-grained, pegmatoid is associated with a mixing area presumably produced by the exsolution of volatile phases from the intruding melanocratic unit.

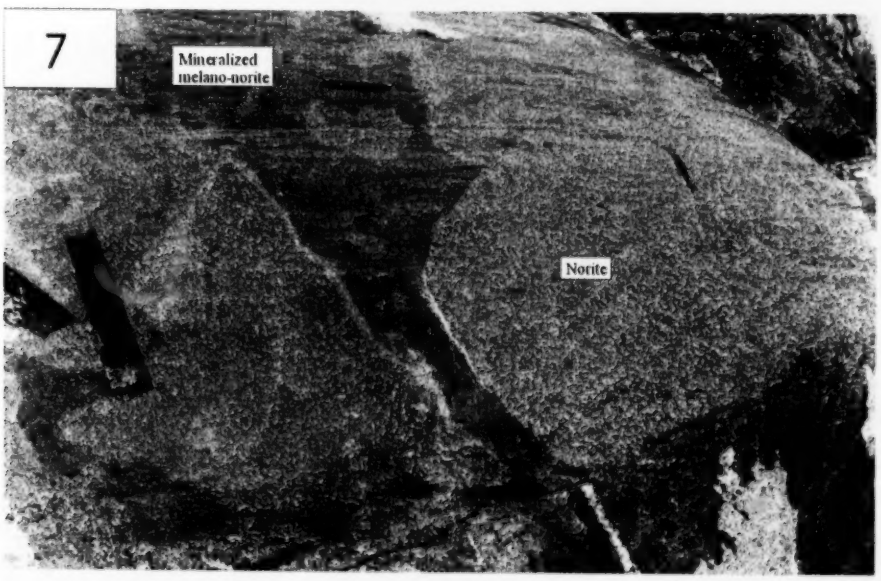


Photo 7. Typical magmatic brecciation characteristics observed within the Twilight Zone where a locally mineralized melanonoritic unit intrudes and essentially brecciates an earlier medium-grained norite. Three distinct noritic units were identified during the summer of 2002.

Twilight Zone

DESCRIPTION OF DIFFERENT UNITS

The Twilight Zone occurs adjacent to the main Roby Zone from which it is separated on its western side by a 50 to 70 m section of the East Gabbro. As with the previously described South Roby Zone, the Twilight Zone shows complicated textures among different lithological units, but the alteration is not as intense and widespread as that in the South Roby Zone.

The Twilight Zone is dominated by relatively unaltered noritic/gabbronoritic intrusions ranging from leucocratic to melanocratic units (Figure 2, *see* back pocket). Different units intruded each other to show magma mingling and multistage breccias (Photo 7). Although noritic/gabbronoritic units dominate, breccias locally include gabbroic clasts. In addition, the south-central section of the Twilight Zone consists of altered gabbroic-clinopyroxenitic intrusions (Photo 8) with local occurrence of a pegmatite unit. The presence of an anorthositic unit, late-stage granitic and diabase intrusions are also common.

Noritic/gabbronoritic intrusions forming the breccia are typically medium grained and are relatively unaltered. Detailed mapping identified at least 3 noritic/gabbronoritic intrusive units within the breccia. These consisted of 1) a medium-grained, relatively unaltered, and typically barren leucocratic noritic unit; 2) a medium-grained, medium-brown, relatively unaltered noritic unit; and 3) a dark brown, melanonoritic to orthopyroxenite unit which contains between 2 and 5% disseminated, chalcopyrite and pyrrhotite blebs. Although the first 2 units were described as being typically barren, these also locally contain significant disseminated chalcopyrite and pyrrhotite when in close association with the melanocratic mineralized breccia unit. The medium-brown noritic unit occurs as clasts in breccias, but also occurs as a massive intrusive phase in the Twilight Zone. The clasts in breccias are dominated by noritic/gabbronoritic units, but gabbroic and anorthositic lithologies also form clasts in the northern extent of the Twilight Zone, and locally elsewhere; both of which are medium grained, moderately to intensely altered, and typically barren.

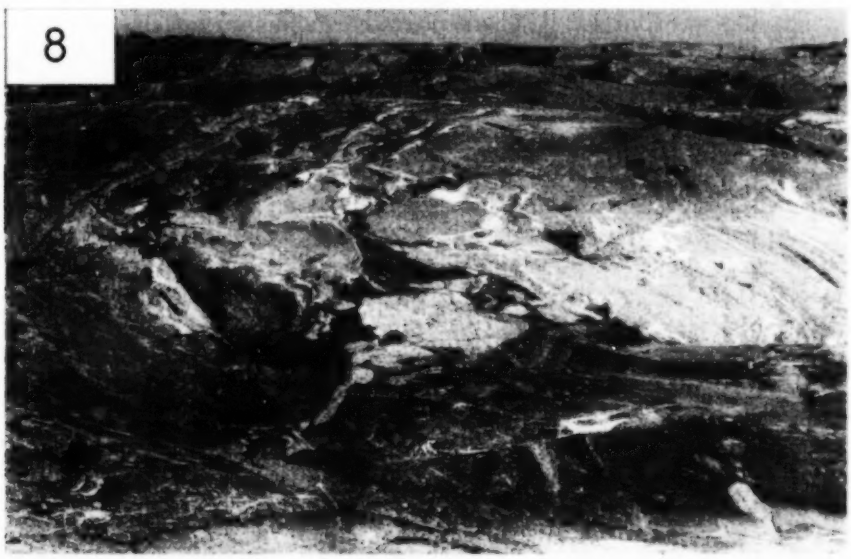


Photo 8. Gabbroic-clinopyroxenitic intrusions occurring in the south-central section of the Twilight Zone. This section shows extensive alteration compared to the surrounding areas where noritic units predominate. These altered units contain pegmatitic pods, similar to those in the South Roby Zone.

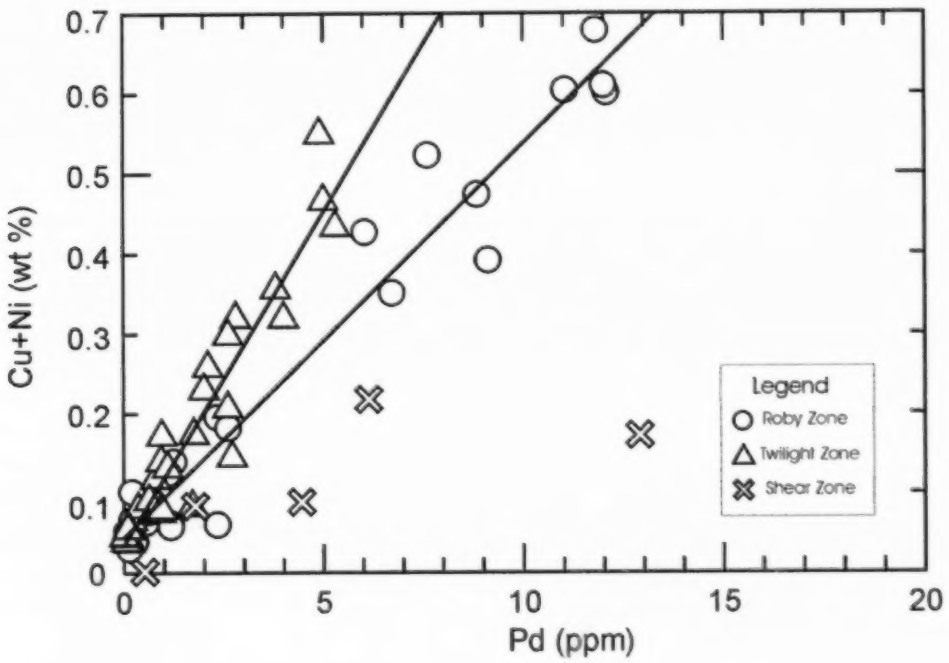


Figure 4. Plot of Pd (ppm) versus Cu + Ni (weight %) for samples from the Roby, Twilight and Shear zones. Note the 2 separate correlation patterns associated with the Roby and Twilight zones. Also note increased scatter in the Roby Zone samples with respect to the Twilight Zone samples. Data sources: Twilight Zone (Foster 2002), Roby Zone (North American Palladium Ltd., unpublished data, 2002), Shear Zone (this study).

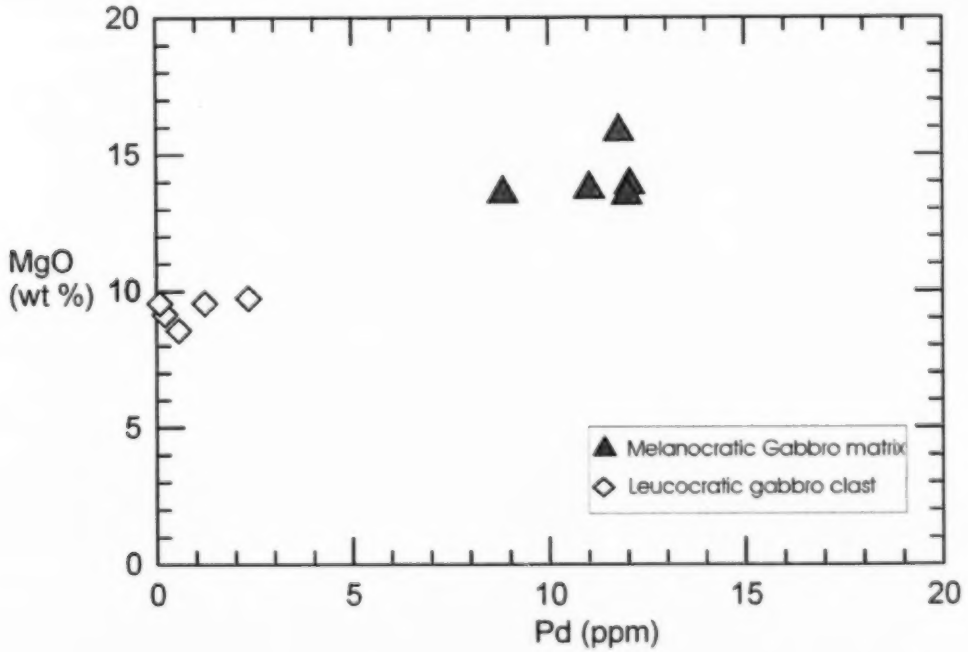


Figure 5. Plot of Pd (ppm) versus MgO (weight %) for the matrix and clast samples collected by M.J. Lavigne in 1999. Locations of samples are shown in Figure 3. Note the melanocratic nature and the increased Pd concentration associated with the melanocratic gabbro matrix.

As mentioned previously, the south-central section of the Twilight Zone consists of medium-grained, medium grey gabbro to medium-grained, massive clinopyroxenite units (*see* Photo 8). The rocks are altered relative to the surrounding noritic/gabbronoritic rocks and show complex textures and breccias. They are spatially associated with a pegmatite unit in the form of veins and pods. The pegmatite unit commonly contains quartz, magnetite, and sulphide minerals dominated by pyrite. The texture and lithologies resemble those of the South Roby Zone. Late granitic and diabase dikes cut all units as observed at the South Roby Zone.

RELATIONSHIPS OF DIFFERENT UNITS IN TWILIGHT ZONE

Contacts of different units are well displayed in the Twilight Zone. Matrix to clast relationships indicate that an earlier leucocratic norite/gabbronorite unit was intruded by the medium-brown norite/gabbronorite unit, which, in turn, was intruded by the melanocratic noritic/gabbronorite-orthopyroxenite unit. The latest melanocratic unit is accompanied by brecciation and mineralization. Magma mingling and the lack of chilled margins indicate successive intrusions within a relatively short time while earlier intrusions were not completely solidified.

In the south-central part of the Twilight Zone, gabbroic-clinopyroxenitic units intruded noritic/gabbronoritic units causing local brecciation of the latter. Minor pegmatitic veins and pods are spatially associated with the gabbroic/clinopyroxenite units. The rocks in this section are altered to form sericite in plagioclase and secondary amphibole and chlorite in amphibole.

Geochemistry

A suite of samples were collected from the Roby Zone (Figure 3, *see* back pocket), by M.J. Lavigne in 1999, to examine the PGE potential of different intrusive units. The Pd contents for the melanocratic rocks from the Roby Zone show a linear array on a Pd versus (Cu+Ni) diagram (Figure 4). The broad positive correlation suggests that the Pd mineralization was likely controlled by the immiscible separation of magmatic sulphide liquid. The data from leucocratic clasts plot on the line defined by the melanocratic units, suggesting that the parental magmas for the 2 types of rocks are likely related.

A plot of Pd versus MgO was constructed for 10 samples (Figure 5), which were collected from the southern portion of the South Roby Zone, as illustrated in Figures 1 and 3. The samples were collected from 5 late, mineralized dark gabbros (unit 7, Figure 1) and 5 early, non-mineralized leucocratic gabbros (unit 4, Figure 1; *see* Figure 3; *see* Photo 3). The dark, melanocratic gabbro is much more primitive and less fractionated than the earlier leucocratic gabbroic rocks as illustrated by its higher MgO content. The melanocratic unit contains much higher Pd than the leucocratic gabbroic unit, suggesting that the PGE mineralization was introduced by the parental magmas for the melanocratic gabbro. Our finding has important implications in the modeling of the Pd mineralization at the Lac des Iles deposit, as discussed below.

Discussion of the Origin of the Palladium Mineralization

Various hypotheses have been proposed for the origin of Pd mineralization at the Lac des Iles intrusive complex. Watkinson and Dunning (1979) proposed that successive magmatic processes and hydrothermal/metamorphic overprinting resulted in the Pd mineralization. Talkington and Watkinson (1984) proposed the importance of later hydrothermal activity for the concentration of PGE based on the occurrence of PGE-bearing tellurides, arsenides, bismuthotellurides and sulphide minerals. Macdonald (1985, 1988) suggested the redistribution of PGE by deuteric fluids derived from volatile-rich parental magmas. Brugmann, Naldrett and Macdonald (1989) and Brugmann and Naldrett (1990a, 1990b) suggested the process of constitutional zone-refining for the enrichment of Pd, which involves scavenging of earlier sulphide minerals by partial melting of earlier cumulates. Michaud (1998) suggested the brecciation and partial melting of earlier gabbroic rocks by volatile-rich magmas and the subsequent enrichment of PGE by percolation of deuteric fluids.

This study suggests that 3 late melanocratic units formed from primitive Mg-rich magma and brought much of the PGE (Photos 3 and 9). Our conclusion is not consistent with the models involving partial melting of co-existing gabbroic rocks because such partial melting would produce less mafic magmas.

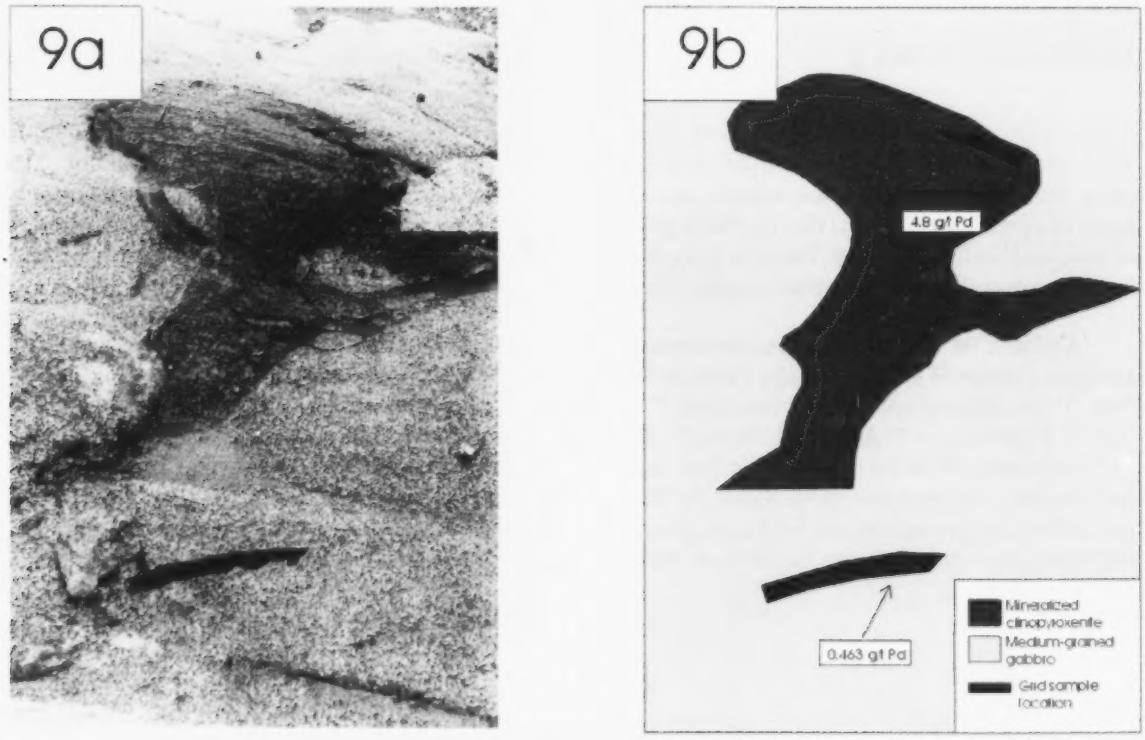


Photo 9. a) Mineralized clinopyroxenitic pod (unit 6, Figure 1) within medium-grained gabbro unit (unit 3, Figure 1) from the central section of the mapped South Roby Zone. b) Sketch from photo illustrating concentration of Pd-mineralization within the clinopyroxenitic unit relative to the massive gabbro unit.

Our study also shows that the Pd mineralization at the Roby Zone is likely to be of magmatic origin based on a positive correlation between Pd and (Cu+Ni) contents (*see* Figure 4). The data from the Roby Zone are compared to those from the Twilight Zone obtained by Foster (2002). The linear correlation defined from the Twilight Zone is steeper than that for the Roby Zone, suggesting that the parental magmas for the intrusions of the Twilight Zone are less mineralized, containing less Pd, than those for the Roby Zone intrusions. In addition, the Roby Zone data display scatter when compared to the well-defined linear trend of data from the Twilight Zone. Although more data are desirable, this scatter is possibly related to late deuteric and/or hydrothermal alteration in the Roby Zone, which mobilized more soluble metals, such as Pd. Data from the Roby Zone were also compared to data obtained from grab samples collected from the high-grade ore zone (commonly referred to as "shear zone ore" by mine personnel) (*see* Figure 4), occurring as a narrow zone (less than 25 m in width) of very altered pyroxenite and heterolithic breccia close to the contact with the East Gabbro (directly east of the main Roby Zone). The high-grade ore samples contain high concentrations of Pd (with relatively low Cu+Ni) and do not plot on the correlation lines for either of the Roby or Twilight zones, suggesting that the Pd mineralization is most likely related to subsolidus hydrothermal activity along a deformation zone. The fluids probably originated from volatile-rich magmas.

The Pd-mineralized units likely formed from fluid-rich parental magmas, judging from the close spatial relationship between the mineralized units and coarse-grained pegmatitic veins and pods. The pegmatite commonly contains sulphide and oxide minerals (magnetite and ilmenite). Some contain quartz, carbonate and hydrous phases, such as biotite. Fluids likely enhanced the growth of coarse crystals and transported PGE. Further supportive evidence of fluid-mobilized PGE is the enrichment of PGE in barren East Gabbro adjacent to the above described high-grade ore zone (North American Palladium Ltd. assay results and J. Rickard, personal communication, 2002). The evidence is consistent with hydrothermal transport of PGE along the deformation zone.

It is proposed that the immiscible separation of fluids from volatile-rich magmas acted both as catalysts for enhanced crystal growth, as observed by the variable textures (i.e., varitextured gabbros, pegmatitic phases, etc.), and provided a mechanism for redistribution and concentration of PGE mineralization. Although much of the mineralization within the intrusive units from the Roby and Twilight zones was likely of primary magmatic origin, localized remobilization of PGE by deuteric/hydrothermal fluids played an important role in the development of the high-grade ore zone and parts of the Roby Zone.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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